THERMAL & FLUIDS
ANALYSIS WORKSHOP
GSFC · 2015

SWOT Loop Heat Pipe Evaporator Joint Conductance Testing

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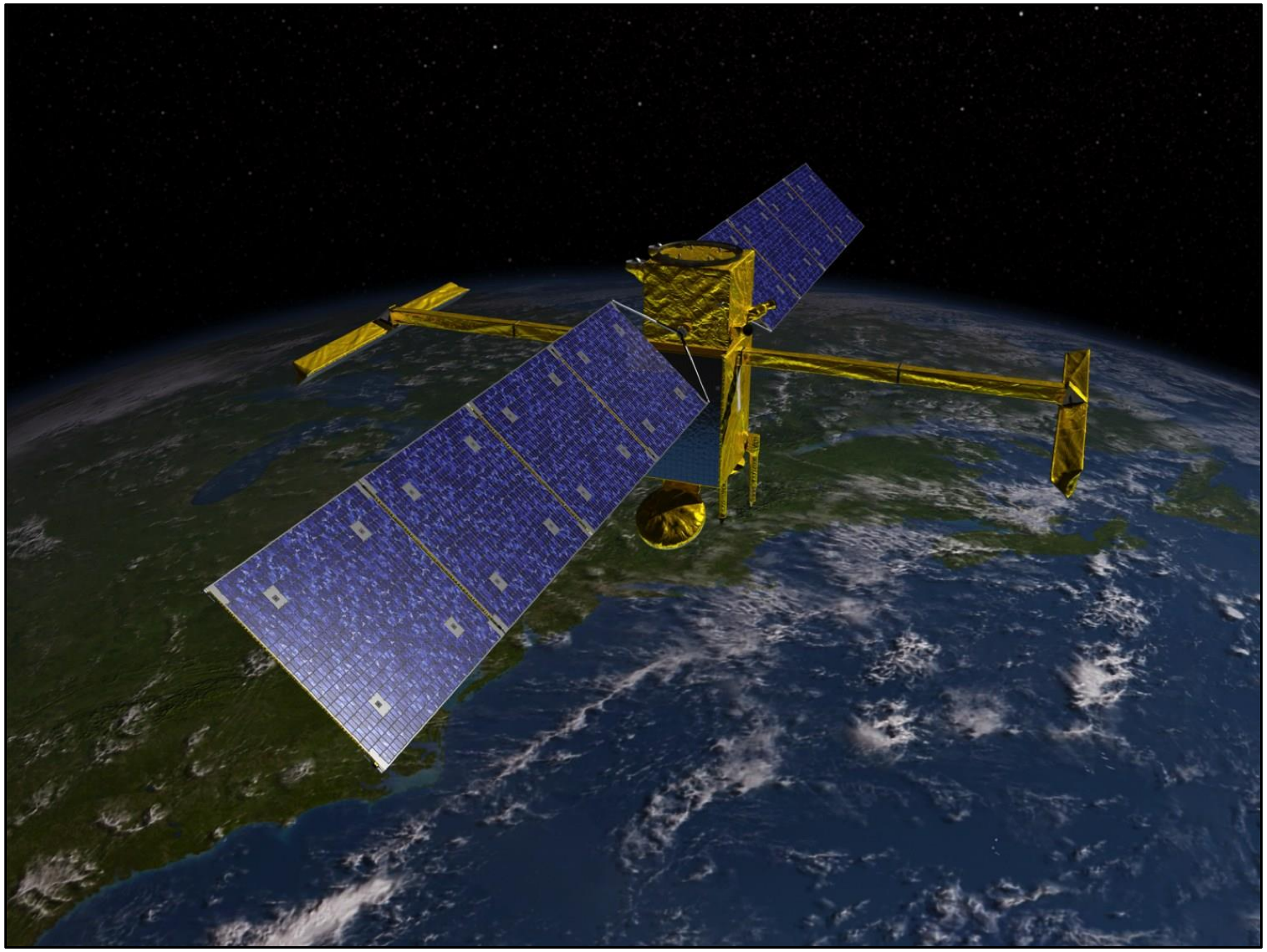
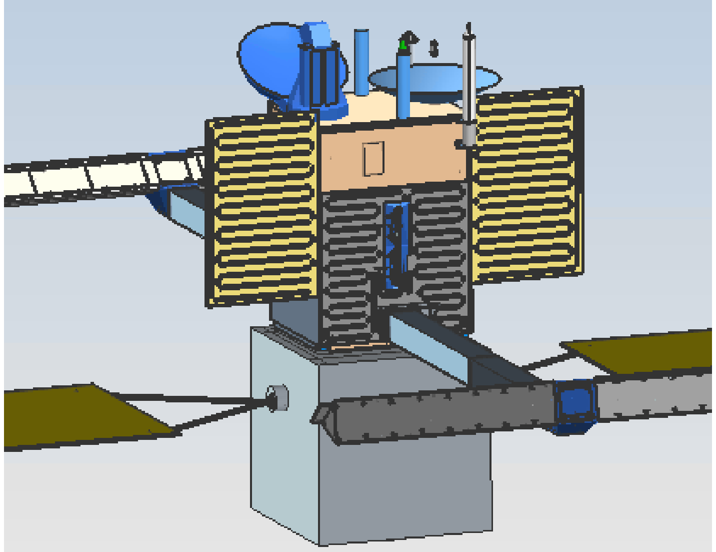
SWOT Mission Background

- Surface Water Ocean Topography (SWOT) will map oceans, lakes, and rivers to increase understanding of the global water cycle

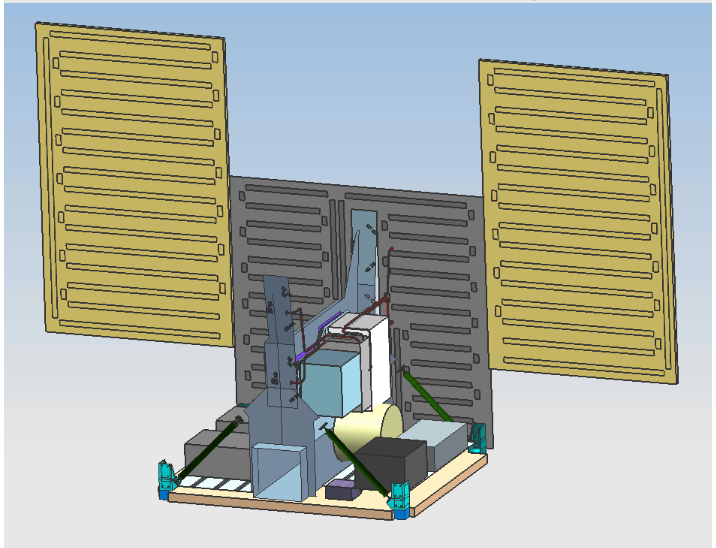


SWOT Thermal Design Background

- Primary Instrument is Ka-Band Radar Interferometer (KaRIn)
  - 1100W dissipation split across four thermal pallets
- The main thermal path for each pallet is first through parallel constant conductance heat pipes (CCHPs) and then through a loop heat pipe (LHP) to the radiator
- Lowering thermal resistance at each interface on the path reduces radiator size, required survival power, and cost



SWOT Observatory



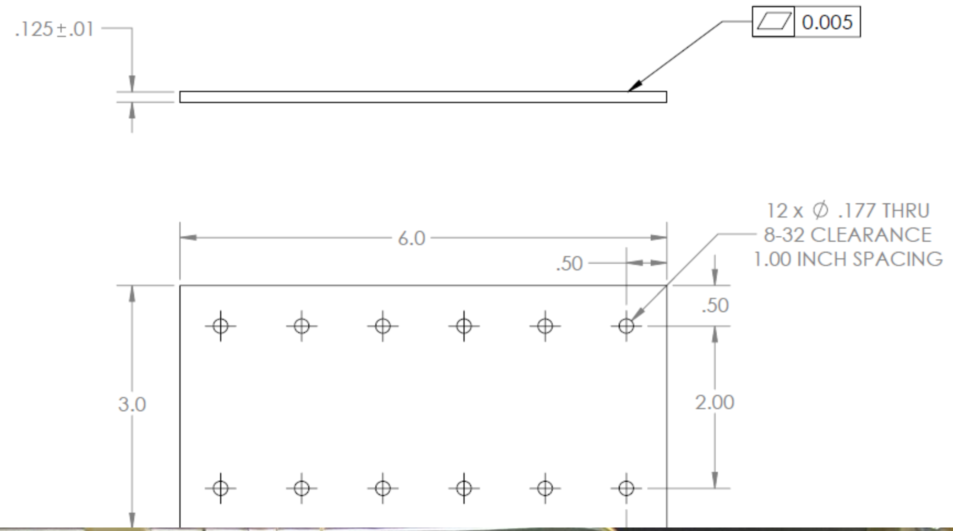
KaRIn

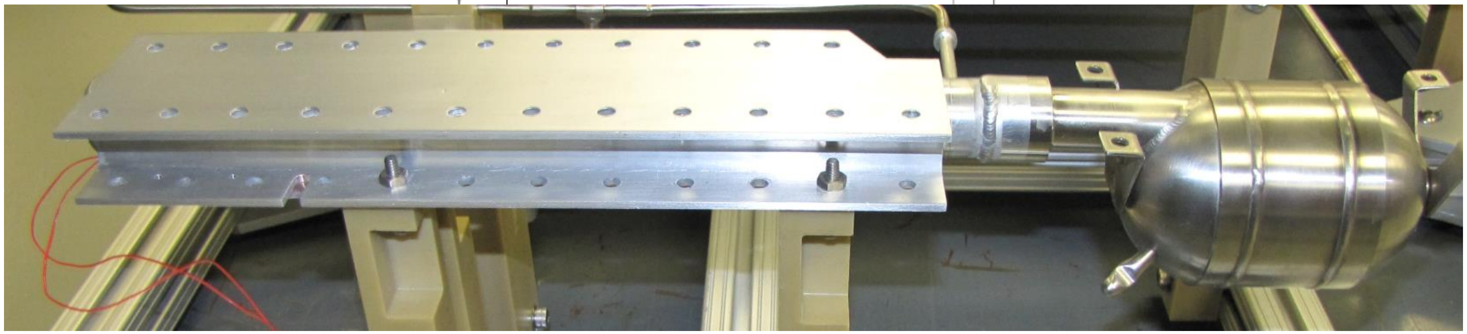
Test Objective

- Characterize thermal conductance of a key thermal interface on SWOT Payload using three candidate materials:
  - Dry bolted interface
  - Graphite foil (eGraf 1220)
  - RTV (CV-2948)
- Rate potential options with the following criteria:
  - Heat transport
  - Integration issues (shedding, deformation)
  - Other issues (outgassing, thermal cycling issues, etc.)
- Baseline interface materials for each flat plate interface on the spacecraft

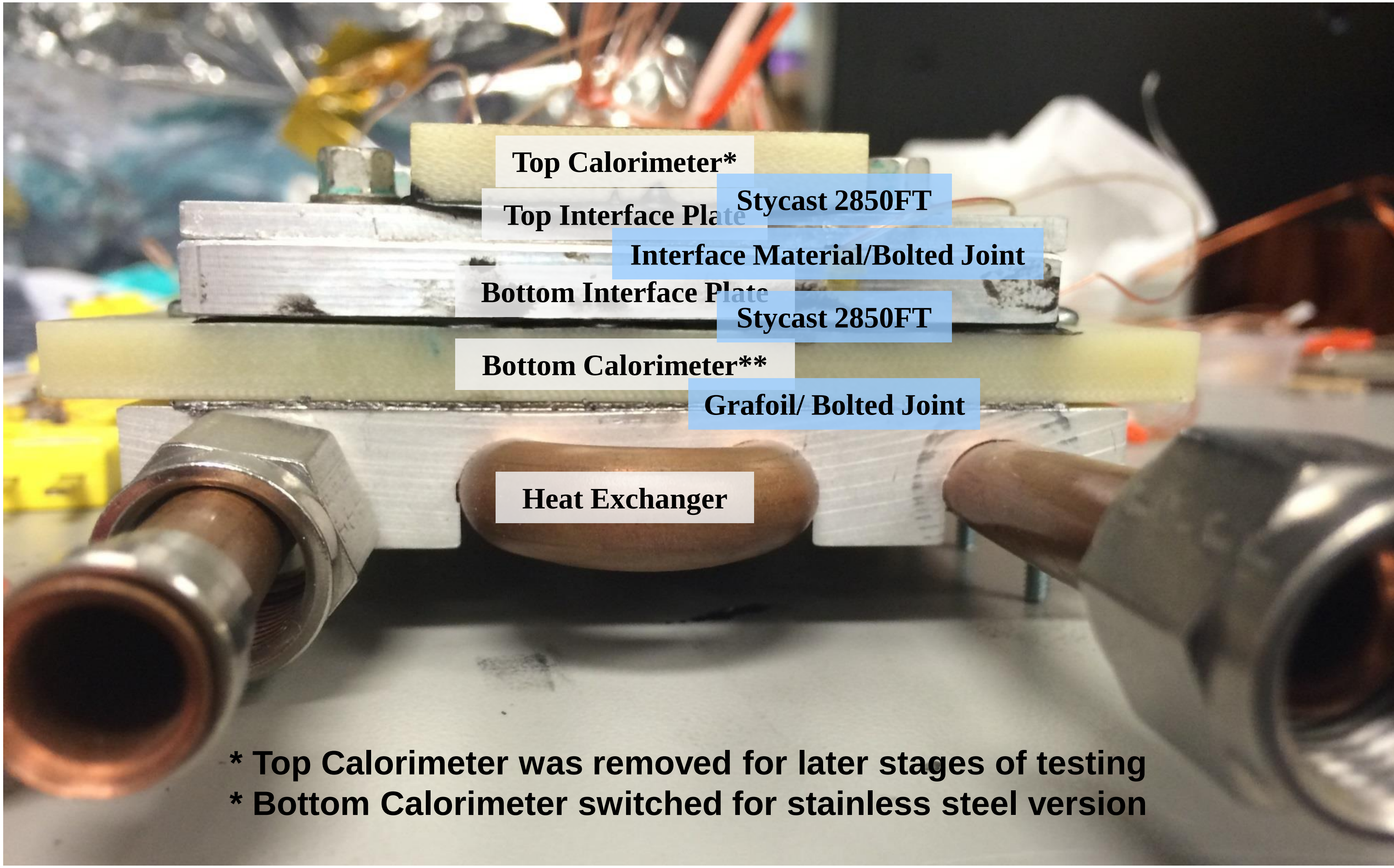
Test Article

- Test article mimics half of the 12” LHP evaporator that is a key interface in the conductive path of the interferometer power dissipation
- Bolt pattern, type, and preload same as in flight (12 #8 bolts)





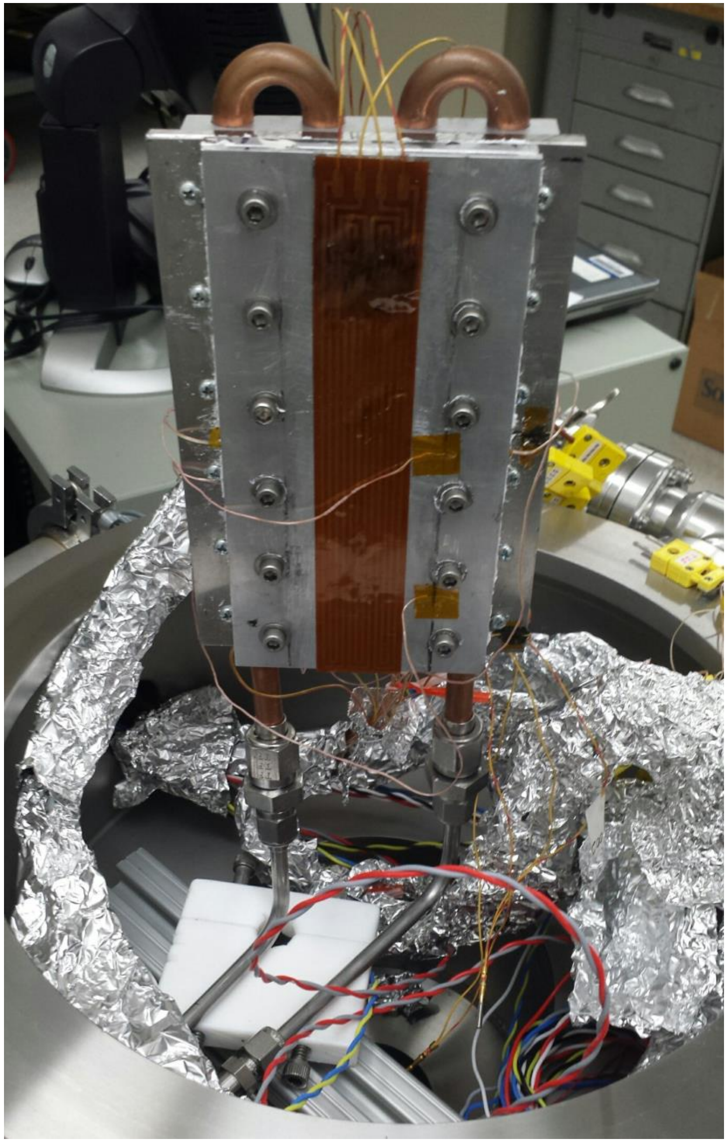
Test Article



*** Top Calorimeter was removed for later stages of testing**
*** Bottom Calorimeter switched for stainless steel version**

Test Architecture

- Heat exchanger was routed to a chiller and controlled at a temperature necessary to keep interface within desired range (-10°C to 50°C)
- Test article was placed in a bell-jar style vacuum chamber at $\leq 7 \times 10^{-5}$ Torr
- Aluminum foil shielded thermocouple wire from electromagnetic interference from the vacuum pump
- 1x6" strip heater applied up to 70W of power to top interface



Conductance Calculation Methods

Two methods were used to calculate interface conductance:

- Method 1: Uses applied power, interface ΔT, and interface area
  - Pros: Simple, requires fewer temperature sensors
  - Cons: High Q_{in} uncertainty due to radiation and electrical losses

$$h_{I/F} = \frac{Q_{in}}{A_{I/F} * \Delta T_{I/F}}$$

- Method 2: Uses stainless steel calorimeter plate
  - Pros: Uses well quantified calorimeter properties
  - Cons: Requires more temperature readings

$$h_{I/F} = \frac{k_{cal} * A_{cal} * \Delta T_{cal}}{t_{cal} * A_{I/F} * \Delta T_{I/F}}$$

Method 1 was used to compare between different interface materials, and Method 2 was used as verification

Material Comparison

- Ideal interface material fills gaps between plates with minimum thickness and high conductivity
- Theoretical limit of interface conductance

$$h_{theo} = \frac{k_{I/F}}{t_{I/F}}$$

Material	Type	Thickness [mil]	k [W/m-K]	h_{theo} [W/m^2-K)
Dry	No interface material	N/A	N/A	infinite
eGraf 1220	graphite foil	20	10	20,000
CV-2948	Silicone	7	1.95	11,000

- Moving from dry to Grafoil to CV-2948
  - Decreases voids when properly installed
  - Can get closer to theoretical interface conductance

Approach and Results

- Each interface was tested at various power levels and temperatures
- Observed trend: higher power → higher h
  - Not accounted for by terms included in uncertainty analysis

Dry

Run	Q_{in} [W]	T_{int} [°C]	h_{int} [W/m²-K]
1	17.5	34	640
2	28.6	27	740
			690

Grafoil

Run	Q_{in} [W]	T_{int} [°C]	h_{int} [W/m²-K]
1	38.8	18	6100
2	49.0	44	7600
3	54.1	43	8700
			7400*

CV-2948

Run	Q_{in} [W]	T_{int} [°C]	h_{int} [W/m²-K]
1	20.0	19	5000
2	25.0	-6	5800
3	40.0	9	6400
4	60.0	20	7200
			6100

*Results calculated using calorimeter method were within uncertainty of this value

Uncertainty Analysis

- Uncertainty in the interface conductance value due to each of the following sources was calculated:

Quantity	Sources of Uncertainty
Heat flow across interface	Radiation from top interface, power supply resistance
Interface Area	Manufacturing tolerance
Interface ΔT	Thermocouple error, electromagnetic interference

- To be conservative, all uncertainty was calculated based on lowest power run for each material

Uncertainty due to	Dry [W/m^2-K]	Grafoil [W/m^2-K]	CV-2948 [W/m^2-K]
Q_{in}	70	360	440
A_{int}	10	240	120
T_{top}	10	1050	670
T_{bot}	10	1050	670
Total	**100**	**2700**	**1900**

Results/Recommendations

- **Dry: 690 ± 100 W/m^2-K**
- **Grafoil: 7400 ± 2700 W/m^2-K**
- **CV-2948: 6100 ± 1900 W/m^2-K**

Option	Thermal Performance	Integration/ Removal	Contamination	Suitable for:
Dry	Poor	Simplest	None	Low power density interfaces
Grafoil	Excellent	Relatively Simple	Shedding Concerns	LHP evaporator, other thermally critical interfaces. Seal edges to reduce shedding concerns
CV-2948	Excellent	Potential Voids, Difficult Removal	No Concerns	Thermally critical interfaces for payloads where Grafoil shedding is unacceptable

- Baseline: Grafoil with sealed edges on critical thermal paths, dry bolted interface elsewhere
- Using measured Grafoil I/F conductances yields acceptable predicted on-orbit thermal performance

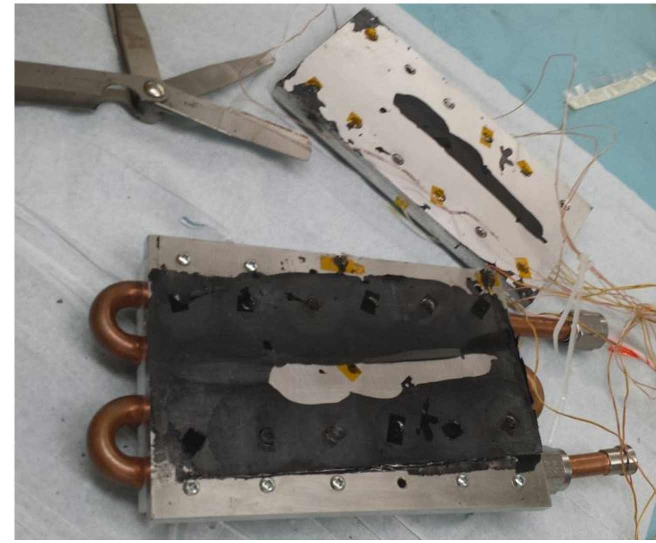
Issues/Lessons Learned

- CTE mismatch on calorimeter/interface plate and heat exchanger
  - Original calorimeter was G10
  - Repeated temperature cycles caused debonding of Stycast

- Excessive vibration from motor on test cart

- Ice in chiller fluid
  - Water condensation formed in the chiller fluid, which froze and stalled the motor at sub-0°C temperatures

- Motor caused unacceptable instability of thermocouple (TC) readings
  - Largely solved by adding aluminum foil shielding to TC wires



Issues/Lessons Learned

- Multiple heater installations led to bubbles and eventual burnout

- Could not replicate the 200W that the half of the LHP evaporator will see in flight.
  - 1x6” heater strip provided up to 70W
  - Lower ΔT across interface meant higher uncertainty in conductance results
  - Retest only if uncertainty level is deemed unacceptable in the future

Credits

Special thanks to:

- Matthew Francom (summer student), who initially worked on this round of testing and provided valuable information for this presentation
- Ruwan Somawardhana (SWOT Thermal CogE), who provided advice, guidance, and assistance during Matthew’s and my stages of testing